Heat-Unit Calculations in Cotton Crop and Insect Models

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ABSTRACT

Heat units are used to characterize the interval between plant and insect events in terms of temperature unit accumulations. Their usefulness is limited to the temperature range in which growth and developmental rates increase linearly with temperatures and do not change significantly with the age of the organism. This publication compares seven different methods of estimating daily heat units from minimum and maximum temperatures with those calculated as the average hourly heat units during the day. The methods range in complexity from the simple mean temperature minus a lower threshold to determining the half-day areas that lie below the minimum-maximum temperature line by triangulation or sine-curve by trigonometry. At midtemperature ranges between the lower and upper thresholds, all the methods obtained nearly the same number of heat units. At lower temperatures, the simple mean method underestimated heat units and overestimated them at higher temperatures. The triangulation and sine-curve methods produced S-shaped heat-unit curves that tend to follow growth temperature curves. Microcomputer algorithms for the seven methods were listed. The triangulation and sine-curve algorithms were simplified to provide maximum utility for predicting crop and insect developmental stages.

KEYWORDS: Temperature, heat unit, degree day, day degree, triangulation, sine-curve, trigonometric algorithms.

CONTENTS

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HEAT-UNIT CALCULATIONS IN COTTON CROP AND INSECT MODELS

By K. E. Fry[1]

INTRODUCTION

The growth and development of plants and insects can be characterized by the number of days between observable events, such as cotton seedling emergence and first squares of the duration of insect generations. The number of days between events, however, may be misleading because growth rates vary with temperatures. The measurement of events can be improved by expressing development units in terms of the temperature and time. The deviation between events is then based on accumulated degrees per unit time above a lower temperature representing a threshold of growth.

Degree days or day degrees can be defined as days in terms of degrees above a threshold. Several methods may be used to calculate degree days, however, each method obtains different values. Because of these differences, I will use the term heat unit (HU) in lieu of degree days for each method. When using HU's to time biological events, nonrandom errors may accumulate because: (1) growth and development rates of the organism do not change linearly with temperature, (2) the rates may vary with the age of the organism (Wang *1960*),[2] and (3) variables other than temperature (for example, nutrient status) may influence the rates. In addition, (4) substantial errors can occur when lower and upper threshold temperatures are not determined correctly or shift with the acclimatization of the organism, (5) small inaccuracies in temperature measurements may result in substantial error when accumulated over an extended period, (6) the calibration of growth-stage HU's for actively transpiring field crops by using temperatures measured at a distance or even in a standard instrument shelter near the field may introduce large HU errors over time, and (7) the experimental timing intervals that are obtained from one method of HU calculations often differ from those obtained with other methods of HU calculations.

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[2]The year in italic, when it follows the author's name, refers to Literature Cited, p. 14.

In this bulletin, I address the last source of error (item 7) by comparing several methods of estimating daily HU's from minimum-maximum temperatures with "observed" HU's in which the hourly degrees above a threshold temperature of 55°F (12.8°C) are summed from the field observations and divided by 24 hr.

HISTORY OF METHODS

A critical review of HU's and their use in plant response studies was presented by Wang (*1960*). The most commonly reported HU was the number of degrees by which the daily mean temperature exceeds a lower threshold or base temperature. In this method, the mean temperature was estimated as the simple average of the minimum and maximum. Thus,

$$HU = ((\text{ minimum} + \text{maximum }) / 2) - 55°F \qquad (1)$$

This is termed the means method of calculating HU's (Arnold *1960*; Wang *1960*; Cross and Zuber *1972*).

Lindsey and Newman (*1956*) introduced a method whereby HU's are calculated as the triangular or trapezoidal areas under the straight lines connecting daily minimum and maximum on a temperature-time plot. Later, Arnold (*1960*) compared the accuracies of calculating HU's using that triangulation method with the means method, and also a trigonometric method whereby a sine-curve is fitted to the daily minimum and maximum temperatures. He reported large errors in the means method and smaller errors in both the triangulation and sine-curve methods. Arnold's comparisons, however, involved only the lower threshold temperature for development, and because only moderate temperatures were used he did not consider situations where high temperatures could retard development.

In cotton growing regions, much higher temperatures are commonly recorded and should be considered when calculating HU's (Wang *1960*). Above an upper threshold or optimum temperature, the rate of plant or insect growth may be constant or may even decrease (Gilmore and Rodgers *1958*; Stinner et al. *1974*; Butler et al. *1978*). In HU algorithms that use temperature means, the maximum temperature is commonly limited to the upper threshold temperature (McKinnion et al. *1975*; Gutierrez et al. *1975*). In the triangulation (Sevecharian et al. *1976*) and sine-curve methods (Allen *1976*), however, the upper threshold has been used as an integral part of the algorithms.

REVIEW OF METHODS

Heat Units From Hourly Temperatures

Air temperatures were sampled every 20 min at 1 m above the cotton crop canopy from March to August 30, 1978, using the data acquisition system described by Fry (*1978*). Three readings were averaged hourly from which the lower

threshold was substracted. The HU's were summed and divided by 24 hr.[3] The HU's estimated by each of the other methods are compared with these daily observed HU's.

Means Method

The means method of calculation involves taking the mean of the daily minimum and maximum temperature and then subtracting a lower threshold temperature (see equation 1). Algorithm 1 in appendix A and figure 1 shows this method in which the HU's increase linearly with an increase in the mean temperature.

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[3] Solid-state devices that automatically sum HU's at 10-min intervals for long periods of time are commercially available. These instruments utilize lower and upper threshold limits.

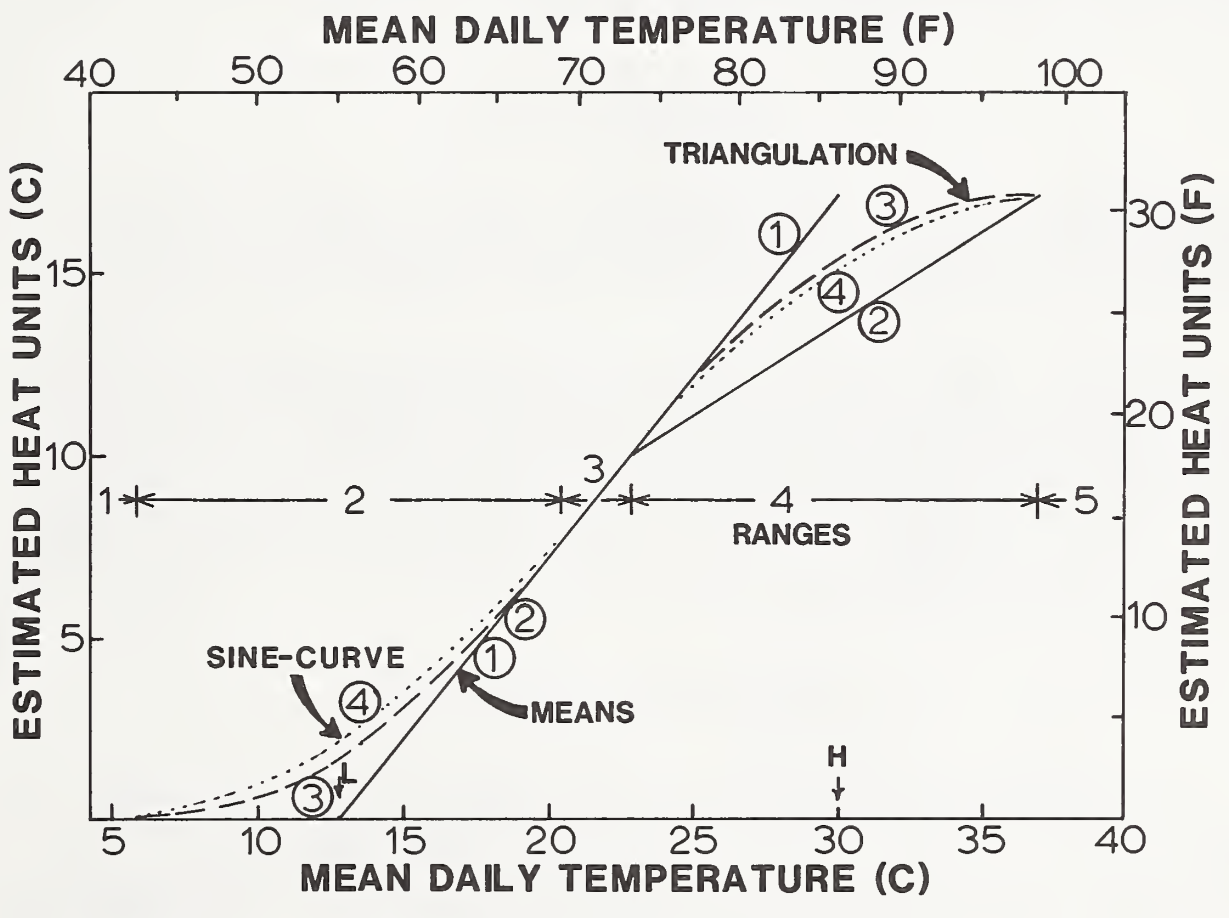


Figure 1.-- Heat units (HU) calculated by the means, triangulation, and sine-curve methods. The continuous line represents the HU's estimated by the means methods, algorithm 1 and 2. The dashed line obtains HU's from the triangulation method, algorithm 4; and the dotted line, from the sine-curve method, algorithm 5. The lower and upper thresholds were 55°F (12.8°C) and 86°F (30°C), respectively, and the swing was 27°F (15°C).

Means Method With Upper Threshold

A second means method is listed in algorithm 2 in which the maximum temperatures are restricted to the upper threshold temperature (line 220 in program) before calculating the HU's as in algorithm 1.

Method From Model SIMCOT II

In the cotton-plant model SIMCOT II, McKinnion et al. (*1974*) utilized separate day (13.2 hr) and night (10.8 hr) temperature means to calculate HU's as in algorithm 3. The combined HU's were similar to those calculated by the means method of algorithm 2, but slightly shifted upward because of a greater number of daylight hours. In addition, they used the concept of the "physiological" day in which a daily mean of 79°F (26°C) equaled one physiological day. Bernhardt and Sheppard (*1978*) derived a similar physiological day from a mean temperature of 81°F (27°C) for Mexican beetles.

Triangulation Method

Sevecharian et al. (*1977*) expanded the triangulation method of Lindsey and Newman (*1956*) to involve an upper threshold. Figure 2 shows six possible minimum-maximum temperature ranges where both thresholds are involved (after Allen *1976*). The shaded areas represent daily or half-day HU's.

Algorithm 4 calculates the areas according to the flow chart in figure 3. In temperature ranges 1 and 5 of figure 2, the accumulated HU's are zero and maximum respectively (line 530). When the maximum temperature is above the upper threshold, the area of the upper triangle D1 (ranges 4 and 6) is calculated using the upper threshold H and the triangulation equation in line 650. Then the ranges 2 and 6 that cross the lower threshold L are selected, and the total area is calculated. The area of the upper triangle is then subtracted from the total area leaving the net HU's (U). Range 3 is calculated as in the means method.

Sine-Curve Method Simplified

A simplification of the sine-curve algorithm is shown in algorithm 5. The range selection routine is identical to that of the triangulation method (algorithm 4). The only difference between the two algorithms is where the trigonometric equations replace the triangulation equation in the mathematical subroutinue. These computer subprograms permit the choice of triangulation or the sine-curve algorithms with minimal programming.

Programmable hand calculators may be utilized to calculate heat units by the triangulation and sine-curve methods. Program listings for the Texas Instrument Company, Model TI-59, are presented in appendix B.

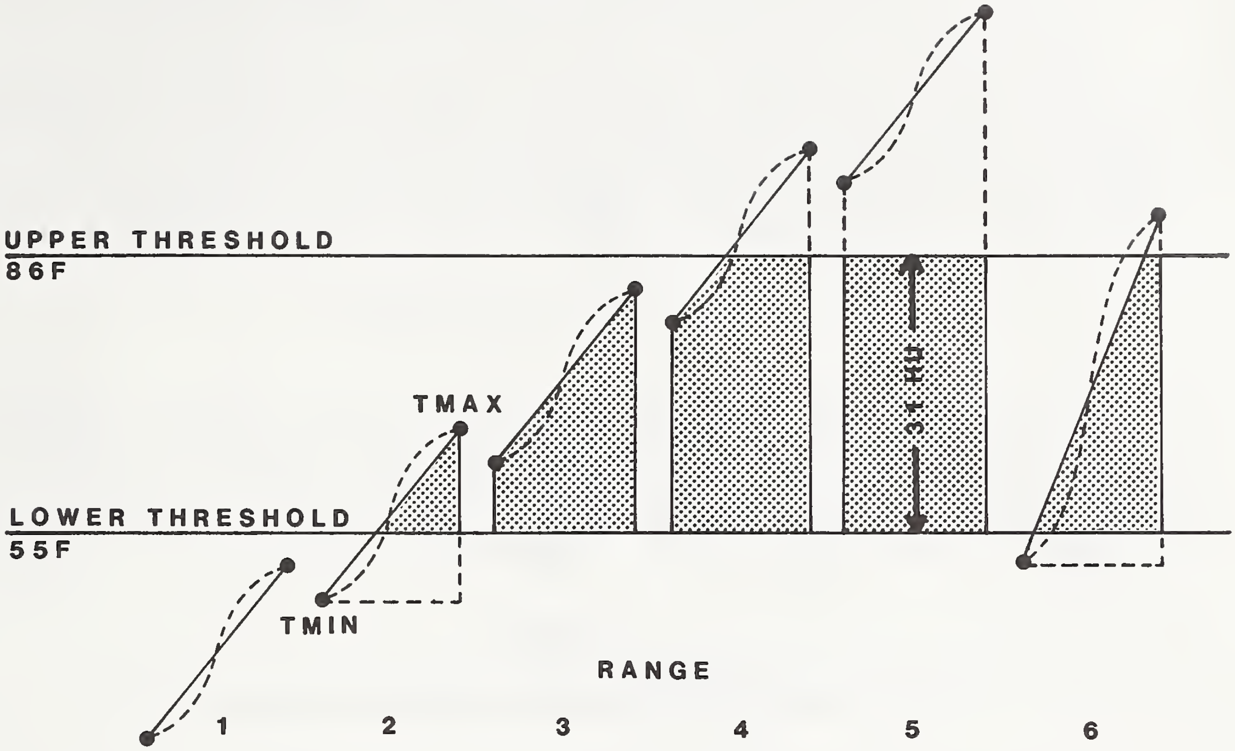
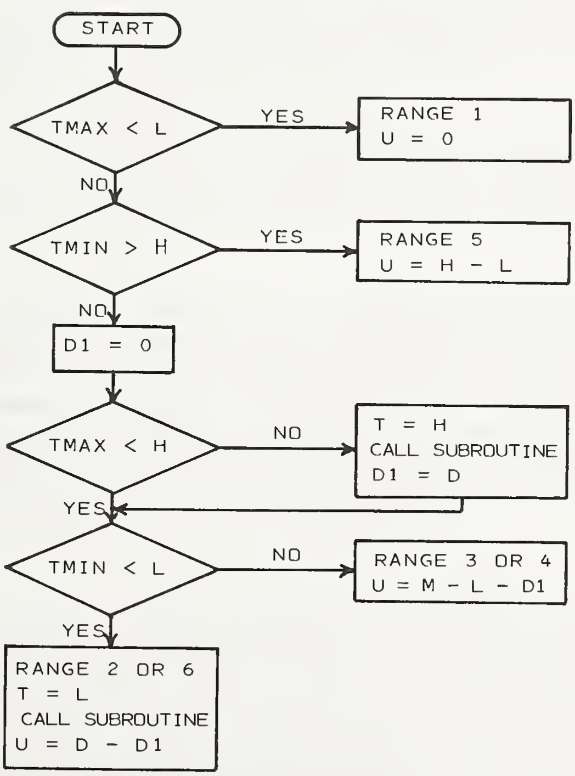


Figure 2.--Temperature ranges related to a lower and upper threshold.



TMIN = DAILY MINIMUM TEMPERATURE
TMAX = DAILY MAXIMUM TEMPERATURE
L = LOWER THRESHOLD TEMPERATURE
H = UPPER THRESHOLD TEMPERATURE
U = HEAT UNITS
M = DAILY MEAN TEMPERATURE
M = (TMAX+TMIN)/2
A = SINE-CURVE AMPLITUDE
B, D, D1, T, Z = TEMPORARY VARIABLES

SUBROUTINE FOR TRIANGULATION
D = (TMAX-T)**2/(2*(TMAX-TMIN))

SUBROUTINE FOR SINE-CURVE
A = TMAX-M :B=T-M :Z=ARCSIN(B/A)
D = (A*COS(Z)-B*((π/2)-Z))/π

Figure 3.--Flow chart for triangulation and sine-curve algorithms.

Sine-Curve Method of Allen

Arnold (*1960*) introduced the concept of using trigonometry to calculate HU's from minimum and maximum temperatures. Baskerville and Emin (*1969*) presented the trigonometric equations for the sine-curve treatment. Allen (*1976*) published algorithms in the computer language FORTRAN for the six temperature ranges (fig. 2) with and without geographical correction regressions. Allen's equations are shown in algorithm 6 with a geographical correction for Arizona.

Method From Model KOTTON

In the plant model KOTTON (Gutierrez et al. *1975*), the higher temperature ranges were treated similarly to the means method with an upper threshold, while the lower temperatures were treated similarly to the sine-curve method (algorithm 7). One degree Fahrenheit (0.55°C) was added to each maximum temperature before proceeding through the algorithm.

RESULTS

Theoretical Differences Between Methods

To facilitate a visual comparison between the two means, the triangulation and the sine-curve methods, HU's were calculated for each method using a constant diurnal temperature swing of 27°F (15°C) and were plotted against the daily mean ((min + max)/2) temperature. The lower threshold was set at 55°F (12.8°C) and the upper at 86°F (30°C) (fig. 1).

The first means method (line 1) calculates highest HU's at the higher temperatures in range 4. By including an upper threshold as in the second means method (line 2), the HU's in range 4 are lowest. Both methods calculate the same HU's in ranges 1, 2, and 3.

The triangulation and sine-curve methods (lines 3 and 4) obtain symmetrical S-shaped HU curves because the areas under the minimum-maximum lines, or sine-curves (fig. 2), change with decreasing rates as the ranges 2 and 4 pass through the lower or upper thresholds, respectively. The HU's differ the most between the triangulation and the sine-curve methods when the mean temperatures are near either the lower or upper threshold (table 1). Figure 1 shows that the triangulation algorithm (4) calculates fewer HU's in range 2, and more units in range 4 than does the sine-curve algorithm (6).

For the other algorithms (3, 5, and 7) in appendix A, the curves (not shown) tend to follow those of the means or sine-curve methods. In the model SIMCOT II, the 55 percent weighting of the day temperature over the night (45) percent temperature caused the HU's to average 0.1 HU above those calculated by the means method (algorithm 2). Calculations by an early KOTTON model (Gutierrez et al. *1975*) follow those of the sine-curve method (algorithm 4) up to the mean temperature at which it switches to the second means method.

Table 1.--*Heat-unit differences between triangulation and sine-curve methods as influenced by average temperatures and daily temperature swings*[1]

Average temperature		Daily temperature swing			
°F	°C	20°F(11.1°C)	30°F(16.7°C)	40°F(22.2°C)	50°F(27.8°C)
		°F	*°F*	*°F*	*°F*
35	(1.7)	0	0	0	-0.43
45	(7.2)	0	- .46	- .93	-1.35
55	(12.8)	.68	-1.02	-1.37	-1.71
65	(18.3)	0	- .46	- .93	-1.03
75	(23.9)	0	.36	.84	- .85
85	(29.4)	.67	1.02	1.36	1.70
95	(35.0)	.07	.56	1.01	1.42
105	(40.6)	0	0	.05	.53

[1]Lower and upper thresholds were 55°F (12.8°C) and 86°F (30°C), respectively.

Table 1 shows the calculated extent the HU's differ between the triangulation and sine-curve methods when both the mean temperatures and swings are known. In addition to the greater differences of HU's at the threshold temperatures, the differences increased as the daily temperature swings between the minimum and maximum increased.

Heat Unit Conversions

Mathematical conversions of HU's between the triangulation and sine-curve methods were investigated but found difficult; however, some field observations in figure 4 were used to indicate that there was a reasonably stable conversion factor (0.97) for the months of June through September. (Sine-curve HU = triangulation HU X 0.97.) During these months, the factor stability is obtained from the relatively uniform daily minimum and maximum temperatures. Consequently, daily changes in the HU's are small when compared with the changes that occur during the spring months.

Observed Heat Units Compared With Calculated Heat Units

The observed HU's were determined from daily sets of hourly field temperatures. In 19 sets, the temperatures were in range 2 between January 3 and

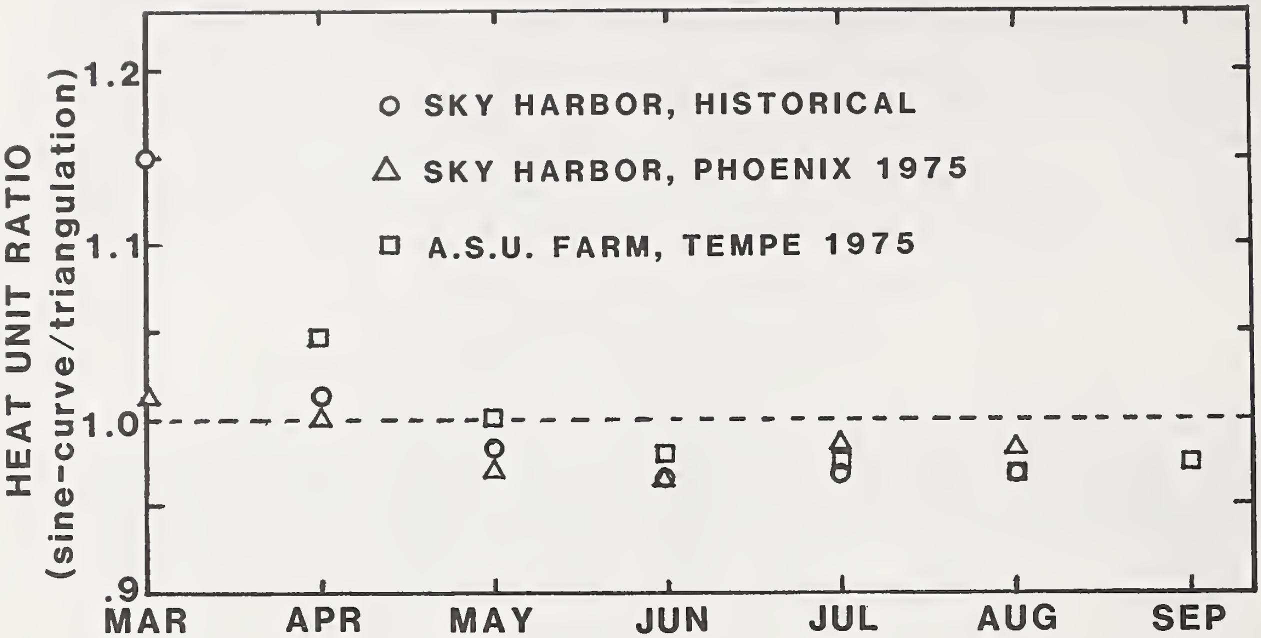


Figure 4.--Ratio of heat units calculated by the sine-curve to the triangulation methods for the months of March to September.

April 8, 1979, while 50 sets fitted range 4 between April 17 and October 11, 1979 and 1980. Of the 70 randomly selected sets, one in range 6 was discarded. Ranges 1, 3, and 5 were not represented in the sets.

The HU's were calculated as described in "Review of Methods" using threshold temperatures of 55°F (12.8°C) and 86°F (30°C). Rates of HU accumulation per day were not allowed to exceed a maximum of the difference between the thresholds. Temperature minimums and maximums were applied to the different algorithms, as listed in appendix A with the resulting HU's shown in table 2.

Without an upper threshold, the first means method overestimated the HU's at higher temperatures in range 4, and underestimated them at low temperatures in range 2. When the maximum temperatures were limited by an upper threshold, as in the second means method, the HU's in range 4 were underestimated.

The routine in SIMCOT II (algorithm 3) obtained nearly the same HU's as did the second means method. The small differences in range 4 results from the bias in favor of the average day temperature for 13.2 hr, which was higher than the night temperature for 10.8 hr.

HU's calculated using the triangulation method were not significantly different from the observed HU's in both ranges. Note that in range 2 the HU's were slightly below the observed and in range 4 they were slightly above.

Table 2.--*Mean daily heat units (HU) and t-values from observed and calculated methods using hourly observations and minimum-maximum temperatures*[1]

Method	Algorithm	Mean HU's Range 2	Mean HU's Range 4	T-values[2] Range 2	T-values[2] Range 4
		°*F*	°*F*		
Hourly observations	-	3.3	13.7	-	-
First means w/o upper threshold	1	2.7	14.7	3.81	6.85
Second means w/upper threshold	2	2.7	12.2	3.81	10.52
Model SIMCOT II	3	2.7	12.3	3.61	10.21
Triangulation	4	3.2	13.8	1.18*	1.26*
Sine-curve (simplified)	5	3.5	13.4	2.93	2.85
Since-curve (Allen's corrections)	6	3.8	13.7	6.00	.14*
Model KOTTON	7	3.5	12.2	2.93	10.52
Number of samples		19	50	-	-

[1]Temperature data were from air sampled 1 m above the cotton crop at Phoenix, in 1978, by the data acquistion system described by Fry (*1978*). Algorithms for calculating the HU's are described in the text and listed in appendix A.

[2]Paired t-test.

*Not significantly different from the observed at P = 0.05.

The simplified sine-curve method obtained HU's that were significantly above the observed in range 2 and below in range 4. The above relationships show that the observed HU's lie between the HU's calculated by the triangulation and the sine-curve methods in both ranges 2 and 4. The HU's from the triangulation method, however, are closer to the observed as shown by the lower t-values.

Allen's geographical corrections to the sine-curve method for Arizona produced an excellent fit of the HU's to the observed in range 4. The same corrections, however, decrease the goodness of fit when applied to range 2 as compared with the simplified and uncorrected sine-curve method.

The HU's calculated by the KOTTON algorithm were identical to those from the second means method in range 4 but followed those from a sine-curve method in range 2. Note the large t-values from the paired t-test in any ranges whenever the means methods were used.

Of the 70 original sets of daily temperatures, 25 sets were selected for days with 100 percent possible sunshine. Plotted in figure 5 are the observed HU's (continuous line) and the HU's for the two means methods, the triangula-

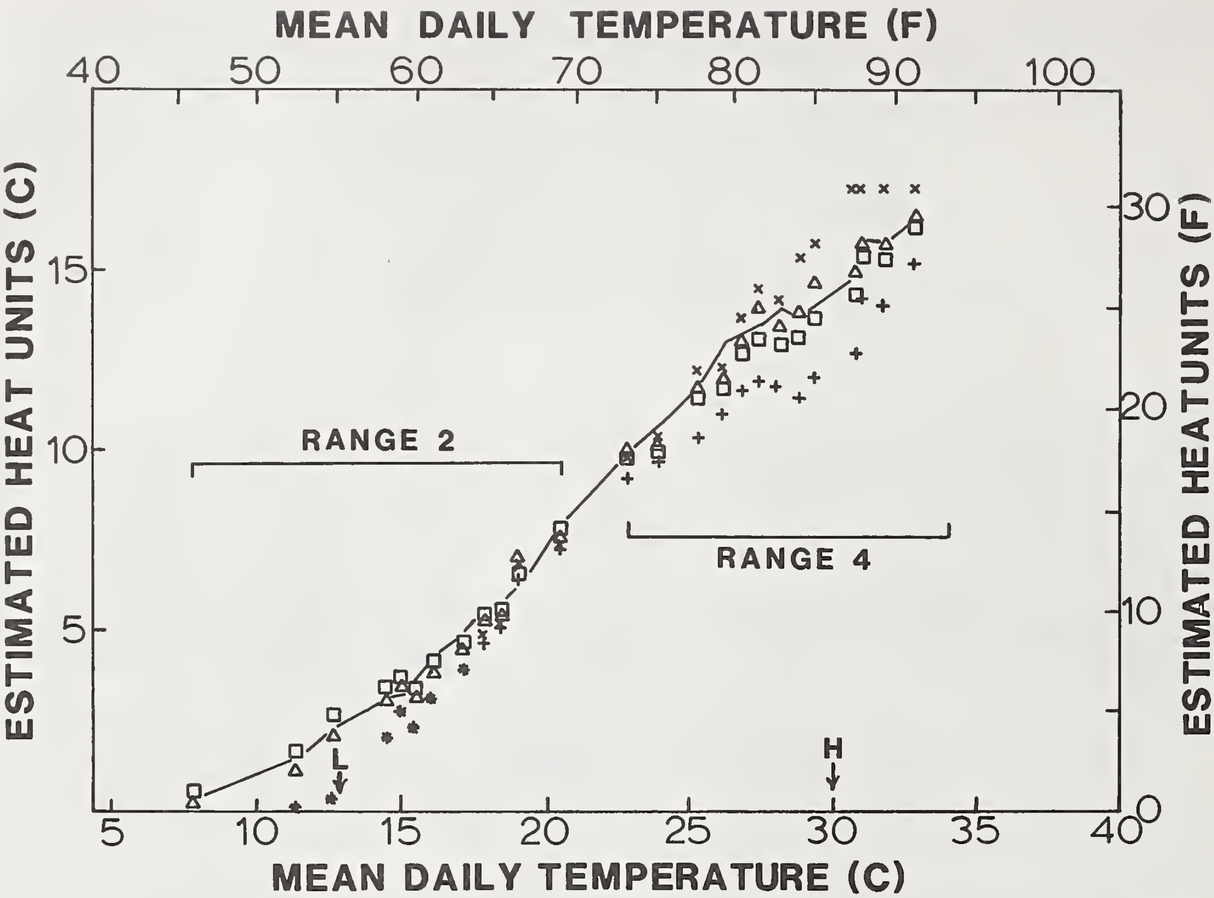


Figure 5.--Heat units (HU) observed and calculated from 25 daily temperature records for days with 100 percent possible sunshine. The continuous line represents the observed HU's as summed from hourly field temperatures. HU's estimated from minimum-maximum temperature are shown for the means method without an upper temperature limit for the maximum (x) and with the upper limit (+), the triangulation method (Δ), and the sine-curve method (□). The average temperature swing was 28.4°F (15.8°C) (SD = 1.98).

tion, and sine-curve methods. HU's calculated by the triangulation and sine-curve methods approximate the observed HU's while the HU's calculated by the means methods depart similarly to the theoretical relationships shown in figure 1.

Data for days with less than 100 percent sunshine were excluded from the plot because the calculated HU's departed from those for sunny days. In range 2, clouds tended to interrupt a smooth rise to and decline from the maximum temperature resulting in fewer HU's calculated. In range 4, cloudy and humid nights, associated with cloudy days, produced warmer nights and higher minimum temperatures, while the adjusted maximum temperatures were constant at the upper threshold with or without the presence of clouds.

Comparison of Daily Heat Units With Half-Day Heat Units

To reduce errors, HU's are often calculated for half-day swings from minimum to maximum temperatures, and then from maximum to minimum temperatures (Gutierrez et al. *1975*; Allen *1976*; and Sevecharian et al. *1976*). This treatment is most useful when the daily mean temperatures are high and are changing rapidly; however, the required number of calculations is doubled. Table 3 shows the total HU's accumulated for the five summer months using the triangulation method in daily and half-day mode. The maximum accumulated differences between the methods at any day were not more than 5 HU, and always occurred during July. Daily positive errors tended to cancel the negative errors so that near the end of the growing season the accumulated error was small. For these data, the error for any day was less than 1 HU 95 percent of the time.

Comparison of Heat-Unit Accumulation Rates

The rates of HU accumulations for the months of the year are shown in table 4. The usefulness of the HU's for timing plant and insect events during the summer months (June to September) may appear to be no greater than the use of the number of days. During these months, the HU's are accumulated at a rapid rate with only a small daily change of rate. If the timing of events is to be compared between years, however, then the use of days alone may lead to misinterpretation of the data when some seasons are cooler and others are warmer than normal. In contrast, during the spring (March-May) and autumn (October-November) months, the daily rates of HU accumulation are changing rapidly. These daily HU's are lower than those accumulated over the summer months. Consequently, the rapid daily changes show a high percentage of change for these periods. Thus, the HU's furnish a convenient timing aid of events that are temperature-sensitive during the spring and autumn months, and for comparisons of results within and between the years.

CONCLUSIONS

Problems of incorrectly estimating HU's can be minimized by using the triangulation or the sine-curve method to calculate HU's from daily minimum and maximum temperatures. These improved methods involve the calculation of areas that lie below either (1) a straight line or (2) a sine curve that extends between the minimum and maximum temperatures and within the boundaries specified by a lower and upper threshold temperature. These areas represent HU's that tend to follow the S-shaped growth rate for plants and insects more closely than do the linear HU's calculated by the means methods. Although the triangulation and sine-curve methods require more complex mathematical calculations than the means methods, look-up charts, programs for hand calculators, and simple computer programs are available for both methods.

Table 3.--*Comparison of daily to half-daily mode of accumulating heat units (HU) from field temperatures using the triangulation method*[1]

Source	Period	Total HU's		Maximum difference	
		Half-daily	Daily	HU's	Date
		°*F*	°*F*	°*F*	
Phoenix (calc.)	3/1-8/30	2114	2117	3.8	7/31/--
Tempe Farm	4/10-8/30	2104	2101	4.7	7/12/75
Phoenix Airport	3/2-8/30	2300	2302	2.6	7/15/78
Phoenix Farm	3/2-8/30	2141	2143	3.3	7/10/78
Parker	3/4-8/30	1995	1997	3.2	7/29/80

[1]Air temperature data were from (1) cubic polynomial regression equation for the mean temperature as determined by the National Weather Service, Sky Harbor International Airport, Phoenix; (2) hygrothermograph in weather shelter at Arizona State University Farm, Tempe; (3) monthly reports from daily weather recorded at Sky Harbor International Airport; (4) air sampled 1 m above the cotton crop canopy by the data acquisition system described by Fry (*1968*); and (5) hygrothermograph in weather shelter at Bruce Church Farm, Parker, Ariz.

Table 4.--*Mean daily temperatures, rates of heat unit (HU) accumulation, and mean daily rate of change of accumulations for each month of the year for Phoenix, Ariz.*[1]

Month	Mean temperature		Mean rate of HU accumulation		Mean daily change of rate		
	°C	*°F*	*°C*	*°F*	*°C*	*°F*	*Percent*
January	10.7	51.2	1.0	1.8	0.014	0.026	1.47
February	12.8	55.1	1.9	3.5	.041	.074	2.14
March	15.4	59.7	3.4	6.2	.076	.137	2.21
April	19.8	67.7	7.1	12.8	.162	.291	1.71
May	24.6	76.3	11.6	20.9	.129	.231	1.11
June	29.2	84.6	14.9	26.8	.040	.072	.27
July	32.9	91.2	16.5	29.7	.013	.023	.08
August	31.7	89.1	16.1	29.0	- .029	- .052	.18
September	28.8	83.8	14.6	26.3	- .035	- .062	.24
October	22.3	72.2	9.5	17.1	- .210	- .377	2.21
November	15.4	59.8	3.5	6.4	- .121	- .218	3.43
December	11.4	52.5	1.3	2.3	- .031	- .057	2.50

[1]Average temperatures were obtained from National Weather Service, Sky Harbor International Airport, Phoenix. HU's were calculated according to the triangulation method described in the text, using lower and upper thresholds of 55°F (12.8°C) and 86°F (30°C), respectively, and a minimum-maximum temperature swing of 27°F (15°C).

LITERATURE CITED

(1) Allen, J. C.
1976. A modified sine wave method for calculating degree days. Environmental Entomology 5:388-896.

(2) Arnold, C. Y.
1960. Maximum-minimum temperatures as a basis for computing heat units. Journal of the American Society of Horticultural Science 76:682-692.

(3) Baskerville, G. L., and Emin, P.
1969. Rapid estimation of heat accumulation from maximum and minimum temperatures. Ecology 50:514-517.

(4) Bernhardt, J. L., and Shepard, M.
1978. Validation of a physiological day equation: Development of the Mexican bean beetle on snap beans and soybeans. Environmental Entomology 7:131-135.

(5) Butler, G. D. Jr., Hamilton, A. G., and Proshold, F. I.
1979. Developmental times of *Heliothis virescens* and *H. subflexa* in relation to constant temperatures. Annual Entomology Society of America 72:263-266.

(6) Cross, H. Z., and Zuber, M. S.
1972. Prediction of flowering dates in maize based on different methods of estimating thermal units. Agronomy Journal 64:351-355.

(7) Fry, K. E.
1978. A minicomputer-controlled data acquisition system. U.S. Department of Agriculture, Science and Education Administration, Advances in Agricultural Technology, AAT-W-1.

(8) Gilmore, E. C., Jr., and Rodgers, J. S.
1958. Heat units as a method of measuring maturity in corn. Agronomy Journal 50:611-615.

(9) Gutierrez, A. P., Falcon, L. A., Loew, W., and others.
1975. An analysis of cotton production in California: A model for Acala cotton and the effects of defoliators on its yield. Environmental Entomology 4:125-136.

(10) Lindsey, A. A., and Newman, J. E.
1956. Use of official weather data in spring time-temperature analysis of an Indiana phenological record. Ecology 37:812-823.

(11) McKinnion, J. M., Baker, D. N., Hesketh, J. D., and Jones, J. W.
1975. SIMCOT II: A simulation of cotton growth and yield. *In* Computer simulation of a cotton production system. U.S. Department of Agriculture, Agricultural Research Service, ARS-S-52.

(12) Sevecharian, V., Stern, V. M., and Mueller, A. J.
1977. Heat accumulation for timing lygus control measures in a safflower-cotton complex. Journal of Economic Entomology 70:399-402.

(13) Stinner, R. E., Gutierrez, A. P., and Butler, G. D., Jr.
1974. An algorithm for temperature-dependent growth rate simulation. Canadian Entomology 106:519-524.

(14) Wang, J. Y.
1960. A critique of the heat unit approach to plant response studies. Ecology 41:785-790.

APPENDIX A: ALGORITHMS FOR METHODS IN BASIC LANGUAGE

The programs on the following pages are written in simple BASIC (with multiple statements), an interpreter language that can be used on most computers. Eight algorithms are combined into a single program for the purpose of comparing the methods of calculation. Each algorithm, however, will run as an individual routine requiring the minimum (T1) and maximum (T2) temperatures, and the lower (L) and upper (H) thresholds. Either temperature system (Fahrenheit or Celsius) may be used after setting the thresholds to the proper values. The trigonometric functions must be run in the radian mode. If the inverse sine function (ARCSIN) is not available in a computer language, an alternative inverse tangent (ARCTAN) may be substituted (see line 860). If necessary, the multiple statement line may be broken into single statement lines at each colon. The SELECT PRINT statements apply to the BASIC language for the minicomputer from Wang Laboratories, Inc., Model 2200S, to select output peripheral devices.

```
1 SELECT PRINT 005 :REM **CRT DISPLAY**
2 PRINT "**********************************************************************"
3 PRINT "* HEAT-UNITS METHODS COMPARED, K.FRY, 7/82,  PROG 'HUCALC'  *"
4 PRINT "* U.S.D.A. AGRICULTURAL RESEARCH SERVICE                    *"
5 PRINT "* COTTON RESEARCH CENTER, 4207 E. BROADWAY RD, PHOENIX, AZ  *"
6 PRINT "* SOURCES ARE IDENTIFIED IN SUBROUTINES                     *"
7 PRINT "* T1=MINIMUM(TMIN), T2=MAXIMUM(TMAX)  U=HEAT UNITS(HU)      *"
8 PRINT "* CHANGE TEMPERATURE THRESHOLDS L & H IN LINES 17, & 19     *"
9 PRINT "**********************************************************************"
11 PRINT
12REM
13 REM **********INITIALIZE**********
14 SELECT PRINT 215(72) :REM                    *LINE PRINTER OUTPUT*
15 P1=3.14159 :SELECT R :REM                    *SELECT RADIAN MODE*
16 PRINT :PRINT :PRINT "                  HEAT-UNIT METHODS COMPARED"
17 PRINT :PRINT "*THRESHOLDS--LOWER(L)  = 12.8 C    55 F"; :L=55
18 PRINT "    L IN USE=";L
19 PRINT "           --UPPER(H)  = 30.0 C    86 F";         :H=86
20 PRINT "    H IN USE=";H
21REM
22 REM ******REPEAT RUNS START HERE******
23 PRINT :SELECT PRINT 005 :PRINT
24 INPUT "KEY TMIN",T1 :INPUT "KEY TMAX",T2
25 U=0 :IF T2>T1 THEN 26 :PRINT "INPUT ERROR, TMIN>=TMAX" :GOTO 24
26 M=(T1+T2)/2 :REM                             *MEAN TEMPERATURE
27 S=T2-T1 :REM                                 *TEMPERATURE SWING
28 SELECT PRINT 215(72)
29 PRINT "TMIN=";T1,"TMAX=";T2,"TMEAN=";M,"SWING";S
30REM
31REM ------ALGORITHM 1------ ( 1ST MEANS METHOD )
100 REM **DAILY MEAN TEMP W/O LOWER THRESHOLD** (FIG 3, LINE 1)
110 REM (ADAPTED FROM ARNOLD, 1960, HORT. SCI. 76 ;682)
120 U=(T1+T2)/2-L :REM                          *HEAT UNITS
130 IF U>0 THEN 140 :U=0 :GOTO 160 :REM         *CHECK FOR NEGS
140 IF U<H-L THEN 160 :REM                      *CHECK FOR >MAX HU
150 U=H-L :REM                                  *MAX HU
160 PRINT "1 MEANS W/ LOWER THRESHOLD",INT(U*100+.5)/100
170REM
180REM ------ALGORITHM 2------ ( 2ND MEANS METHOD )
200 REM **DAILY MEAN TEMP W/ LOWER THRESHOLD** (FIG 3, LINE 2)
210 REM (ADAPTED FROM ARNOLD, 1960, HORT. SCI. 76 ;682)
220 T5=T2 :IF T5<=H THEN 230 :T5=H :REM         *TMAX UPPER LIMIT
230 U=(T1+T5)/2-L :REM                          *HEAT UNITS
240 IF U>0 THEN 250 :U=0 :GOTO 270 :REM         *CHECK FOR NEGS
250 IF U<H-L THEN 270 :REM                      *CHECK FOR >MAX HU
260 U=H-L :REM                                  *MAX HU
270 PRINT "2 MEANS W/ LO & UP THRESHOLD",INT(U*100+.5)/100
280REM
```

```
290REM ------ALGORITHM 3------
300 REM **FROM 'SIMCOT II' CROP MODEL**
310 REM (ADAPTED FROM MCKINION ET AL. 1975, USDA, ARS-S-52)
320 L5=13.2 :REM                                   *DAYLNGTH= 13.2 HRS
330 T5=T2 :IF T5<H THEN 340 :T5=H :REM             *TMAX LIMIT
340 M1=T5-T1 :REM                                  *TEMP SWING
350 L6=L5/24 :L7=(24-L5)/24 :REM                   *DAY & NITE TIME FAC
360 D5=M1*L6+T1 :N5=M1*L7+T1 :REM                  *AVG DAY & NITE TEMPS
370 D6=(D5-L)*L6 :IF D5>L THEN 380 :D6=0 :REM *DAY HU
380 N7=(N5-L)*L7 :IF N5>L THEN 390 :N7=0 :REM *NITE HU
390 U=D6+N7 :REM                                   *HEAT UNITS
400 PRINT "3 'SIMCOT II'= DAY+NITE",INT(U*100+.5)/100
410REM
420REM ------ALGORITHM 4------ ( RECOMMENDED TRIANGULATION METHOD )
500 REM **TRIANGULATION METHOD SIMPLIFIED, K. FRY** (FIG 3, LINE 3)
510 REM (BASED ON SEVACHARIAN ET AL. 1977. J. ECON. ENT. 70: 399)
520 M=(T1+T2)/2 :REM                               *TEMP AVG
530 IF T2<L THEN 600 :IF T1>H THEN 610 :REM        *TEST FOR RANGES 1 & 5
540 D1=0 :IF T2<H THEN 560 :REM                    *SEP 2 & 3 FROM 4 & 6
550 T=H :GOSUB 650 :D1=D :REM                      *AREA UPPER TRIANGLE
560 IF T1<L THEN 570 :U=M-L-D1 :GOTO 590 :REM *RANGES 3 & 4
570 T=L :GOSUB 650 :REM                            *AREA TOTAL TRIANGLE
580 U=D-D1 :REM                                    *RANGES 2 & 6
590 IF U>0 THEN 620 :REM                           *CHECK FOR NEGS
600 U=0 :GOTO 620 :REM                             *RANGE 1
610 U=H-L :REM                                     *MAX HU, RANGE 5
620 PRINT "4 TRIANGULATION METHOD",INT(U*100+.5)/100 :GOTO 720
630REM
640 REM **TRIANGULATION EQUATION (SUBROUTINE)**
650 D=(T2-T)↑2/(2*(T2-T1)) :RETURN
660REM
670REM ------ALGORITHM 5------ ( RECOMMENDED SINE-CURVE METHOD )
700 REM %**SINE-CURVE METHOD SIMPLIFIED, K. FRY** (FIG. 3, LINE 4)
710 REM (ADAPTED FROM ALLEN 1976, & SEVECHARIAN ET AL. 1977)
720 M=(T1+T2)/2 :REM                               *TEMP AVG
730 IF T2<=L THEN 800 :IF T1>H THEN 810 :REM       *TEST FOR RANGES 1 & 5
740 D1=0 :IF T2<H THEN 760 :REM                    *SEP 2 & 3 FROM 4 & 6
750 T=H :GOSUB 850 :D1=D :REM                      *AREA UPPER TRIANGLE
760 IF T1<L THEN 770 :U=M-L-D1 :GOTO 790 :REM *RANGES 3 & 4
770 T=L :GOSUB 850 :REM                            *AREA TOTAL TRIANGLE
780 U=D-D1 :REM                                    *RANGES 2 & 6
790 IF U>0 THEN 820 :REM                           *CHECK FOR NEGS
800 U=0 :GOTO 820 :REM                             *RANGE 1
810 U=H-L :REM                                     *MAX HU, RANGE 5
820 PRINT "5 SINE-CURVE (SIMPLIFIED)",INT(U*100+.5)/100 :GOTO 920
830REM
840 REM **SINE-CURVE EQUATIONS (SUBROUTINE)**
850 A=T2-M :B=T-M :Y=B/A :Z=ARCSIN(Y)
860 REM *ARCSIN(Y) EQUIV=  Z=ARCTAN(Y/SQR(1.0001-Y↑2))
870 D=(A*COS(Z)-B*(P1/2-Z))/P1 :RETURN
880REM
```

```
890REM ------ALGORITHM 6------
900 REM %**ALLEN'S SINE-CURVE W/ CORRECTIONS**
910 REM (CORRECTIONS FOR ARIZONA, ALLEN, 1976, ENV. ENTOMOL. 2; 388)
920 M=(T1+T2)/2 :A=T2-M :Y1=(L-M)/A :Y2=(H-M)/A
930 V=(.08884*A)-.28187 :REM                         *CORREC FAC FOR ARIZONA
940 IF T2>L THEN 960
950 R=1 :U=0 :GOTO 1060 :REM                                *RANGE 1
960 IF T1<H THEN 980
970 R=5 :U=H-L :GOTO 1060 :REM                              *RANGE 5
980 IF T2>H THEN 1020 :IF T1>=L THEN 1010
990 R=2 :F=(T2-L)/(T2-T1) :REM                              *RANGE 2
1000 Z1=ARCSIN(Y1) :Z2=P1/2 :GOTO 1050
1010 R=3 :U=M-L+V :GOTO 1060 :REM                           *RANGE 3
1020 Z2=ARCSIN(Y2) :IF T1<L THEN 1040
1030 R=4 :F=(H-T1)/(T2-T1) :Z1=-P1/2 :GOTO 1050 :REM *RANGE 4
1040 R=6 :F=(H-L)/(T2-T1) :Z1=ARCSIN(Y1) :REM         *RANGE 6
1050 U=(((M-L)*(Z2-Z1)+(COS(Z1)-COS(Z2))*A+(H-L)*(P1/2-Z2))*1/P1)+(V*F)
1060 PRINT "6 SINE-CURVE (W/ ALLEN'S COREC)",INT(U*100+.5)/100,
1070 PRINT "TEMP RANGE=";R
1080REM
1090REM ------ALGORITHM 7------
1100 REM %**FROM 'KOTTON' CROP MODEL**
1110 REM (ADAPTED FROM GUTIERREZ ET AL. 1975. J. ENV. ENT. 4; 125)
1120 F5=1 :REM                              *CONVERT FAC(F5)=1.8 C, 1.0 F
1130 T5=T2+F5 :IF T5<H THEN 1140 :T5=H
1140 U=0 :IF T5-1<=L THEN 1180
1150 T=T1+T5-(2*L) :IF T1<L THEN 1160 :U=T/2 :GOTO 1180
1160 Y=(T/(T1-T5)) :Z=ARCSIN(Y)
1170 U=(1/(2*P1)*((T5-T1)*COS(Z)-T*Z))+(T/4)
1180 PRINT "7 'KOTTON'(MEANS/SINE COMBO)",INT(U*100+.5)/100
1190REM
1200 GOTO 22 :REM                                  *REPEAT RUN
```

```
                 HEAT-UNIT METHODS COMPARED

*THRESHOLDS--LOWER(L)  = 12.8 C    55 F    L IN USE= 55
           --UPPER(H)  = 30.0 C    86 F    H IN USE= 86

TMIN= 40         TMAX= 70         TMEAN= 55        SWING 30
1 MEANS W/ LOWER THRESHOLD         0
2 MEANS W/ LO & UP THRESHOLD       0
3 'SIMCOT II'- DAY+NITE            .83
4 TRIANGULATION METHOD             3.75
5 SINE-CURVE (SIMPLIFIED)          4.77
6 SINE-CURVE (W/ ALLEN'S COREC)    5.3              TEMP RANGE= 2
7 'KOTTON'(MEANS/SINE COMBO)       5.19

TMIN= 55.5       TMAX= 85.5       TMEAN= 70.5      SWING 30
1 MEANS W/ LOWER THRESHOLD         15.5
2 MEANS W/ LO & UP THRESHOLD       15.5
3 'SIMCOT II'- DAY+NITE            15.65
4 TRIANGULATION METHOD             15.5
5 SINE-CURVE (SIMPLIFIED)          15.5
6 SINE-CURVE (W/ ALLEN'S COREC)    16.55            TEMP RANGE= 3
7 'KOTTON'(MEANS/SINE COMBO)       15.75

TMIN= 71         TMAX= 101        TMEAN= 86        SWING 30
1 MEANS W/ LOWER THRESHOLD         31
2 MEANS W/ LO & UP THRESHOLD       23.5
3 'SIMCOT II'- DAY+NITE            23.58
4 TRIANGULATION METHOD             27.25
5 SINE-CURVE (SIMPLIFIED)          26.23
6 SINE-CURVE (W/ ALLEN'S COREC)    26.75            TEMP RANGE= 4
7 'KOTTON'(MEANS/SINE COMBO)       23.5

TMIN= 87         TMAX= 112        TMEAN= 99.5      SWING 25
1 MEANS W/ LOWER THRESHOLD         31
2 MEANS W/ LO & UP THRESHOLD       31
3 'SIMCOT II'- DAY+NITE            31.5
4 TRIANGULATION METHOD             31
5 SINE-CURVE (SIMPLIFIED)          31
6 SINE-CURVE (W/ ALLEN'S COREC)    31               TEMP RANGE= 5
7 'KOTTON'(MEANS/SINE COMBO)       31.5

TMIN= 50         TMAX= 90         TMEAN= 70        SWING 40
1 MEANS W/ LOWER THRESHOLD         15
2 MEANS W/ LO & UP THRESHOLD       13
3 'SIMCOT II'- DAY+NITE            13.18
4 TRIANGULATION METHOD             15.11
5 SINE-CURVE (SIMPLIFIED)          15.22
6 SINE-CURVE (W/ ALLEN'S COREC)    16.38            TEMP RANGE= 6
7 'KOTTON'(MEANS/SINE COMBO)       13.8
```

APPENDIX B: HEAT-UNIT PROGRAMS FOR POCKET CALCULATOR

HU's may be calculated and accumulated on the programmable pocket calculator, Texas Instrument TI-59, with the following program. Either the triangulation or the sine-curve subroutine may be attached to the main program, which selects the proper temperature range as shown in figure 2. Print commands are included in the listing for use with a printer but are not necessary for operation. With the aid of the HU flow chart in figure 3, this program may be adapted to other programmable calculators.

TITLE HEAT-UNIT METHODS PAGE 1 OF 3 **TI Programmable Program Record**

PROGRAMMER K. FRY, USDA, ARS DATE AUGUST 1982

Partitioning (Op 17) 4,7,9,5,9 Library Module NOT USED Printer PC-100A Cards 1 SIDE

PROGRAM DESCRIPTION

THIS PROGRAM WILL CALCULATE DAILY HEAT UNITS BASED ON MINIMUM AND MAXIMUM TEMPERATURES USING THE MEANS, TRIANGULATION, OR THE SINE-CURVE METHOD. LINES 0-11 INPUT THE TEMPERATURE DATA, LINES 12-33 CALCULATE HEAT UNITS BY THE MEANS METHOD, LINES 34-120 SELECT TEMPERATURE RANGES AND CALCULATE HEAT UNITS USING EITHER THE TRIANGULATION (SUBROUTINE LINES 178-195) OR THE SINE-CURVE METHOD (SUBROUTINE LINES 196-239). INITIALIZATION AND PRINT-OUT UTILITIES ARE LISTED FROM LINE 121 TO 167.

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
1	LOAD PROGRAM					
2	INITIALIZE (HU SUM = 0)		2ND	E'		THUP
3	KEY MINIMUM TEMPERATURE	TMIN		A		TMIN
4	KEY MAXIMUM TEMPERATURE	TMAX		B		TMAX
5	HEAT UNITS - MEANS METHOD			C		HU
6	PRINT AVERAGE TEMPERATURE		2ND	A'		TAVG
	(STEPS 5 & 6 MAY BE SKIPPED)					
7	HEAT UNITS - TRIANGULATION			D		HU
	(SINE-CURVE METHOD MAY BE SUBSTITUTED BY CHANGING SUBROUTINE ADDRESSES AT LINES 72-4 AND 99-101 TO SBR 196)					
8	PRINT ACCUMULATED HEAT UNITS			E		HU SUM
	(THE PROGRAM WILL OPERATE WITH OTHER LOWER AND UPPER TEMPERATURE THRESHOLDS BY CHANGING THE VALUES IN LINES 146-149 AND 156-159).					

USER DEFINED KEYS		DATA REGISTERS (INV List)			
A	TMIN	0	THUP-THLO	0	
B	TMAX	1	TMIN	1	
C	HU (MEANS)	2	TMAX	12	HU SUM (MEANS)
D	HU (TRIANG)	3	TAVG	13	HU SUM (TRIANG)
E	HU SUM	4	D2	4	
A'	AVERAGE TEMP	5	SINE-CURVE EQ	5	
B'		6	"	6	
C'		7	"	7	
D'		8	LOWER THRESH.	8	
E'	INITIALIZE	9	UPPER THRESH.	9	

LABELS (Op 08)

INV	lnx	CE	CLR	x:t	x^2
$\sqrt{x}$	1/x	STO	RCL	SUM	y^x
EE	(	)	÷	GTO	×
SBR	−	RST	+	R/S	.
+/−	=	CLR	INV	log	CP
tan	Pgm	P→R	sin	cos	CMs
Exc	Prd	|x|	Eng	Fix	Int
Deg	Pause	x=t	Nop	Op	Rad
Lbl	x≥t	Σ+	$\bar{x}$	Grad	St flg
If flg	D.MS	π	List	Write	Dsz
Adv	Prt				

FLAGS	0	1	2	3	4	5	6	7	8	9

 1014966-1

TITLE HEAT-UNIT METHODS PAGE 2 OF 3

PROGRAMMER K. FRY, USDA, ARS DATE

TI Programmable Coding Form

LOC	CODE	KEY	COMMENTS
0	76	LBL	KEY
	11	A	MINIMUM
	42	STO	TEMP
	01	01	
	99	PRT	(TMIN)
	91	R/S	
	76	LBL	KEY
	12	B	MAXIMUM
	42	STO	TEMP
	02	02	
10	99	PRT	(TMAX)
	91	R/S	
	76	LBL	MEANS
	13	C	METHOD
	43	RCL	W/O UPPER
	00	00	THRESHOLD
	32	X ≷ T	
	71	SBR	GET
	01	01	(TAVG)
	68	68	
20	75	−	
	43	RCL	
	08	08	
	95	=	
	22	INV	MAX HU
	77	GE	LIMITED
	00	00	TO
	29	29	H-L
	32	X ≷ T	
29	44	SUM	
30	12	12	
	99	PRT	
	98	ADV	
	91	R/S	
	76	LBL	Δ & ∿
	14	D	AREA
	71	SBR	METHODS
	01	01	
	68	68	GET TAVG
	42	STO	
40	03	03	
	25	CLR	
	42	STO	
	04	04	
	43	RCL	
	02	02	
	32	X ≷ T	
	43	RCL	
	01	01	
	77	GE	TMIN > =
50	01	01	TMAX ?
	10	10	GOTO 110
	43	RCL	
	08	08	
	77	GE	THLO > =

LOC	CODE	KEY	COMMENTS
	01	01	TMAX ?
	10	10	GOTO 110
	43	RCL	
	09	09	
	32	X ≷ T	
60	43	RCL	
	01	01	
	77	GE	TMIN >=
	01	01	THUP ?
	16	16	GOTO 116
	43	RCL	
	02	02	
	22	INV	
	77	GE	TMAX <
	00	00	THUP ?
70	77	77	GOTO 77
	32	X ≷ T	
72	71	SBR	GET AREA
	01	01	OF UPPER
74	78	78	TRIANGLE
	42	STO	(D1)
	04	04	
77	43	RCL	
	08	08	
	32	X ≷ T	
80	43	RCL	
	01	01	
	22	INV	
	77	GE	TMIN <
	00	00	THLO ?
	97	97	GOTO 97
	43	RCL	
	03	03	
	75	−	
	32	X ≷ T	
90	75	−	
	43	RCL	
	04	04	
	95	=	HU =
	61	GTO	TAVG −
	01	01	THLO −
	06	06	DL
97	43	RCL	
	08	08	
99	71	SBR	GET AREA
100	01	01	OF TOTAL
101	78	78	TRIANGLE
	75	−	(D)
	43	RCL	
	04	04	
	95	=	HU = D-D1
106	29	CP	(CLEAR T)
	77	GE	HU > 0 ?
	01	01	GOTO 111
	11	11	

LOC	CODE	KEY	COMMENTS
110	25	CLR	RANGE 1
111	44	SUM	OUT
	13	13	
	99	PRT	
	98	ADV	
	91	R/S	STOP
116	43	RCL	RANGE 5
	00	00	
	61	GTO	
	01	01	
120	11	11	
121	76	LBL	PRINT
	16	A'	TAVG
	71	SBR	
	01	01	
	68	68	
	99	PRT	
	98	ADV	
	91	R/S	
129	76	LBL	PRINT
130	15	E	HU SUMS
	43	RCL	
	12	12	
	99	PRT	
	43	RCL	
	13	13	
	99	PRT	
	98	ADV	
	91	R/S	
139	76	LBL	INITIAL-
140	10	E'	IZE
	25	CLR	
	42	STO	
	12	12	
	42	STO	
	13	13	
146	05	5	LOWER
	05	5	THRESH-
	93	.	OLD
149	00	0	°F
150	42	STO	
	08	08	
	99	PRT	
	94	+/-	
	42	STO	
	00	00	
156	08	8	UPPER
	06	6	THRESH-
	93	.	OLD
159	00	0	°F

MERGED CODES

62 Pgm Ind	72 STO Ind	83 GTO Ind
63 Exc Ind	73 RCL Ind	84 Op Ind
64 Prd Ind	74 SUM Ind	92 INV SBR

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TI-24151

TITLE HEAT-UNIT METHODS PAGE 3 OF 3

TI Programmable Coding Form

PROGRAMMER K. FRY, USDA, ARS DATE

LOC	CODE	KEY	COMMENTS
160	42	STO	
	09	09	
	99	PRT	
	44	SUM	THUP -
	00	00	THLO
	98	ADV	
	70	RAD	
167	91	R/S	
168	43	RCL	AVERAGE
	01	01	TEMP
170	85	+	SUBR.
	43	RCL	
	02	02	
	95	=	
	55	÷	
	02	2	
	95	=	
	92	RTN	
178	94	+ / -	TRIANGU-
	85	+	LATION
180	43	RCL	SUBR.
	02	02	
	95	=	
	33	x^2	
	55	÷	
	53	(	
	02	2	
	65	X	
	53	(	
	43	RCL	
190	02	02	
	75	−	
	43	RCL	
	01	01	
	95	=	
195	92	RTN	
196	75	−	SINE-
	43	RCL	CURVE
	03	03	SUBR.
	95	=	
200	42	STO	
	05	05	
	55	÷	
	53	(	
	43	RCL	
	02	02	
	75	−	
	43	RCL	
	03	03	
	54	)	
210	42	STO	
	06	06	
	95	=	
	22	INV	
	38	SIN	

LOC	CODE	KEY	COMMENTS
	42	STO	
	07	07	
	43	RCL	
	06	06	
	65	X	
220	43	RCL	
	07	07	
	39	COS	
	75	−	
	53	(	
	43	RCL	
	05	05	
	65	X	
	53	(	
	89	π	
230	55	÷	
	02	2	
	75	−	
	43	RCL	
	07	07	
	95	=	
	55	÷	
	89	π	
	95	=	
239	92	RTN	

LOC	CODE	KEY	COMMENTS

MERGED CODES

62 Pgm Ind	72 STO Ind	83 GTO Ind
63 Exc Ind	73 RCL Ind	84 Op Ind
64 Prd Ind	74 SUM Ind	92 INV SBR

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